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RESEARCH MEMORANDUM

EFFECT OF FUEL ADDITIVES ON CARBON DEPOSITION

IN A J33 SINGLE COMBUSTOR

IV - NINE OXYGEN-BEARING COMPOUNDS

By Edmund R. Jonash, William P. Cook, and Jerrold D. Veear

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CLASSIFIED DOCUMENT

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EFFECT OF FUEL ADDITIVES ON CARBON DEPOSITION IN A J33 SINGLE COMBUSTOR

IV - NINE OXYGEN-BEARING COMPOUNDS

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SUMMARY

The effectiveness of nine oxygen-bearing additives in reducing carbon formation in a single tubular-turbojet-engine combustor was investigated. The additives included four alkyl nitrates, one alkyl nitrite, two nitro compounds, an ether, and a peroxide. Different concentrations of the additives were blended with No. 2 furnace oil. Carbon deposits were measured for combustor operation at conditions simulating a 20,000-foot flight altitude, zero flight speed, and 90-percent rated engine speed in a J33 turbojet engine. In addition, the effects of the additives on smoke concentration in the combustor exhaust gases were determined.

The oxygen-bearing additives were generally less effective in reducing carbon deposits than a number of organo-metallic additives tested in previous investigations. Only four of the compounds, three alkyl nitrates, and diethyl ether, reduced deposits significantly. The largest reduction, 30 percent, was obtained with a 1.0 percent by weight concentration of iso-octyl nitrate. None of the additives had a significant effect on exhaust-gas-smoke concentration.

INTRODUCTION

The use of fuel additives to reduce deleterious carbon formation in turbojet-engine combustion chambers is being investigated at the NACA Lewis laboratory. The relative effectiveness of 15 organo-metallic compounds is reported in references 1 to 3. A number of these additives, particularly those containing combined lead or iron, substantially reduced carbon deposits in a single tubular combustion chamber. Although the mechanism by which the reductions occurred is not understood, it has been suggested that metallic oxide resulting from combustion of an organo-metallic compound may interchange its oxygen with the carbon formed on the walls of the chamber leaving reduced metal on the walls. In tests with fuels containing metal compounds some traces of the metal have been observed on the walls, together with substantial amounts of the metallic oxide.

Metallic deposits formed by organo-metallic additives may be as harmful as carbon deposits. For example, lead has been observed to cause corrosion in the turbojet engine. For this reason nonmetallic, oxygenated compounds that may promote the oxidation of carbon deposits without forming harmful residues have been suggested. Some success has been obtained with alkyl nitrates, particularly amyl nitrate (ref. 4).

The investigation reported herein was conducted to determine the effectiveness of four alkyl nitrates, amyl nitrite, nitropropane, nitrobenzol, tert-butyl hydroperoxide, and diethyl ether in reducing carbon deposits in a single turbojet combustor. The additives were blended with a No. 2 furnace oil. Deposits were measured for combustor conditions simulating operation of a full-scale engine at 90-percent rated engine speed, zero flight speed, and an altitude of 20,000 feet. The relative effectiveness of these additives and the organo-metallic additives of references 1 to 3 are compared.

As a secondary part of this investigation, the effects of the additives on the concentration of smoke in the combustor exhaust gases were determined. The tests were conducted at the same conditions used for the deposit studies.

FUELS AND ADDITIVES

Two different batches of No. 2 furnace oil were used as base fuels in this investigation. Their physical and chemical properties varied somewhat (table I). The blends of additive and base fuel tested are as follows:

Base fuel	Additive	Concentration	
		Percent by weight of blend	Percent by volume of blend
NACA 53-193	<u>n</u> -Propyl nitrate	0.5	0.41
	<u>n</u> -Propyl nitrate	1.0	.82
	Amyl nitrate	.5	.43
	Amyl nitrate	1.0	.86
	Iso-octyl nitrate	.5	.45
	Iso-octyl nitrate	1.0	.90
NACA 55-89	<u>n</u> -Butyl nitrate	3.7	3
	Amyl nitrite	2.76	2.73
	2-Nitropropane	3.5	3
	Nitrobenzol	4.2	3
	<u>tert</u> -Butyl hydroperoxide	3.1	3
	Diethyl ether	2.5	3

Initial tests were conducted with additive concentrations of 0.5 and 1.0 percent by weight. Results of the first series of tests with base fuel 53-193 indicated only moderate reductions in deposits with the alkyl nitrates. Consequently, the remaining additives were tested at the higher concentration of 3 percent by volume. The supply of amyl nitrite limited the concentration of this additive to 2.73 percent by volume. The amyl nitrite was a mixture of 29.4 percent by weight iso-amyl nitrite and 70.6 percent by weight n-amyl nitrite. All additives tested were liquids and were readily soluble in the furnace oil.

APPARATUS AND PROCEDURE

The J33 single combustor (fig. 1) and test facility (fig. 2) used in the additive investigations of references 1 to 3 were used for the study reported herein. The air-supply and exhaust systems are shown in figure 2. The fuel was pumped through a calibrated rotameter and injected into the combustor through a J33 production nozzle. Inlet-air and exhaust-gas temperatures and pressures were measured with conventional thermocouple and total-pressure probes (ref. 5).

The combustor operating conditions were as follows:

Inlet-air pressure, in. Hg abs	53.9
Inlet-air temperature, °F	271
Air flow, lb/sec	2.87
Fuel flow, lb/hr	127.3
Fuel-air ratio	0.0123

At these conditions the average combustor-exhaust-gas temperature was approximately 1100° F.

Prior to the test run, the combustor liner and dome, the ignition plug, and the fuel nozzle were cleaned with rotating wire brushes; the liner and dome and the ignition plug were weighed on a torsion-type balance, then reweighed after 4 hours of operation at the combustor operating conditions. The difference in weight before and after the test run, together with the weight of carbon formed on the fuel nozzle, was considered the amount of carbon deposited.

Qualitative measurements of the amount of smoke in the exhaust gases were made. At intervals during the test run gas samples were withdrawn from a total-pressure probe centrally located in the exhaust duct and passed through a filter-type smoke meter (ref. 6).

After each test with a fuel-additive blend, the fuel system was drained and purged with the base fuel to remove any residual additive. One or more check runs with the base fuel were made between tests with each of the additives to determine the effectiveness of the purge and the reproducibility of the base-fuel deposits.

RESULTS AND DISCUSSION

Carbon Deposits

The carbon-deposit data obtained with the No. 2 furnace oil and the fuel-additive blends are presented in table II in the order in which they were obtained. Base fuel 53-193 alone gave an over-all average deposit of 35.6 grams. The mean deviation in individual test runs from this average was 10 percent; the maximum deviation was 20 percent. The same fuel gave an average deposit of 20.5 grams in the study reported in reference 2, and 28.3 grams in the study reported in reference 3. The large difference in deposits obtained with fuel 53-193 in references 2 and 3 is probably attributed to aging, which would increase the gum content of the fuel. There is no apparent reason for the large difference in deposits obtained with fuel 53-193 in reference 3 and in the present study.

Fuel 55-89 gave an over-all average deposit of 19.8 grams. The mean and maximum deviations in individual test runs for this fuel were 8 and 19 percent, respectively. The higher smoke-volatility index and smoke point, and the lower NACA K factor of fuel 55-89 (see table I) would predict somewhat lower deposits than with fuel 53-193. The large reduction in deposits observed with fuel 55-89 may also be partially attributed to its lower gum content (table I).

Multiple additive-test runs were conducted with three alkyl nitrates only because supplies of the other additives were limited. For these multiple tests the mean deviation of deposits in individual test runs from the average deposit values varied from 1 to 13 percent. The deviations observed with the base-fuel and the additive-fuel blends were within the range expected in carbon-deposit studies (ref. 7).

Of the oxygenated materials tested only four, 0.5 percent by weight n-propyl nitrate, 1.0 percent by weight iso-octyl nitrate, 1.0 percent by weight amyl nitrate, and 2.5 percent by weight diethyl ether, significantly reduced the deposits of furnace oil (table II). The largest reduction was 30 percent, obtained with a 1.0 percent by weight concentration of iso-octyl nitrate. While three of the alkyl nitrates reduced deposits, n-butyl nitrate caused the largest increase in deposits (57 percent). Since the effects of additive concentrations measured with the other alkyl nitrates were not self-consistent, the cause of increased deposition by a 3.7 percent by weight concentration of n-butyl nitrate can not necessarily be attributed to the high concentration.

A comparison of the relative effectiveness of the additives tested in references 1 to 3 and in the present study is presented in figure 3. Average carbon deposits in percentage of base-fuel deposits are shown only for the additive concentrations that gave the largest reduction in deposit. All tests were conducted at the same operating conditions in

the same combustor. In general, the oxygenated compounds were considerably less effective than the organo-metallic compounds. The most effective oxygenated compound, iso-octyl nitrate, reduced base fuel deposits 30 percent, while the most effective organo-metallic compound, dicyclopentadienyliron, reduced base-fuel deposits about 80 percent. Additive A, the most effective of the commercial additives, reduced base-fuel deposits 74 percent. A qualitative spectroscopic analysis of additive A showed that it contained lead and copper. Iron and lead compounds, iron pentacarbonyl and tetraethyl lead, also reduced deposits (ref. 8) in a small-scale atomizing combustor. The weights of deposits reported include any metallic deposits. Therefore, actual reductions in carbon deposits obtained with the organo-metallic additives may have been significantly greater than reported.

A comparison of results obtained with a number of additives (A, D, and lead naphthenate) that were tested in more than one base fuel indicate that the relative effectiveness of an additive varies with the base fuel. For example, additive A in No. 2 furnace oil reduced deposits 74 percent (ref. 2); the same concentration of additive A in the same furnace oil with an increased gum content reduced deposits 57 percent (ref. 3); and the same additive in a low-quality (high carbon-forming) JP-4 fuel reduced deposits 48 percent (ref. 2). The experimental data do not indicate a relation between the effectiveness of an additive and the carbon-forming propensity of the fuel.

The effectiveness of an additive may also be expected to vary with the combustor design. In reference 8 the two additives that reduced deposits in an atomizing combustor (iron pentacarbonyl and tetraethyl lead) also decreased deposits in the combustion zone of a vaporizing-type combustor, but increased deposits inside the vaporizing tubes. It is interesting to note (ref. 8) that injection of distilled water into the vaporizing tubes was the only effective method of reducing deposits within the tubes.

Exhaust-Gas Smoke

The exhaust-gas-smoke data obtained with the furnace oil and fuel-additive blends are presented in table II. The smoke ratings for the furnace oil varied from $2\frac{1}{2}$ to $4\frac{1}{2}$ on a scale of 0 to 9. The smoke ratings obtained with the additive blends were within the range obtained with the base fuel. Thus, no effect of the additives on smoke concentration was apparent. Similar results were obtained with organo-metallic additives in the studies of references 2 and 3.

Combustion Efficiency

Combustion efficiencies were not computed for the deposition tests reported herein. However, comparisons of fuel-flow rates and combustor temperature rise indicated no effect of the additives on combustion efficiency. Similar results were obtained in references 2 and 3. The operating conditions chosen for the deposition tests assured high combustion efficiencies (above 94 percent). Under these conditions, possible effects of the additives on efficiency might not be detected.

CONCLUDING REMARKS

Previous investigations showed that a number of organo-metallic compounds effectively reduced carbon deposits in a single turbojet-engine combustor. Since the decomposition products of at least some of these additives have been found to cause harmful corrosion in combustor and turbine components of some turbojet engines, the present study was undertaken to find effective nonmetallic additives. From a group of nine nonmetallic, oxygenated additives tested, the best, an alkyl nitrate, was considerably less effective than several of the metallic additives. However, this investigation was limited in scope and other nonmetallic compounds or different concentrations of those tested may result in more effective reduction in deposits.

SUMMARY OF RESULTS

The following results were obtained from the determination of the relative effectiveness of the nine oxygen-bearing additives in reducing carbon formation of No. 2 furnace oil in a single turbojet combustor:

1. Three alkyl nitrates and diethyl ether reduced carbon deposits significantly. The largest reduction, 30 percent, was obtained with a 1.0 percent by weight concentration of iso-octyl nitrate.
2. No significant reductions in deposition were obtained with the fourth alkyl nitrate, a nitrite, two nitro compounds, or a peroxide.
3. None of the additives tested significantly affected the concentration of smoke in the combustor exhaust gases.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 1, 1955

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TABLE I. - ANALYSES OF NO. 2 FURNACE OILS

Fuel properties	NACA fuel	
	53-193	55-89
A.S.T.M. distillation D86-46, °F		
Initial boiling point	356	378
Percentage evaporated		
5	406	408
10	430	426
20	460	448
30	482	468
40	500	485
50	516	500
60	530	516
70	548	532
80	564	554
90	590	580
Final boiling point	622	613
Residue, percent	1.5	2.0
Loss, percent	0	0
Freezing point, °F	-15	2
Aromatics, percent by volume	30	22.4
Bromine number	6	5.4
Potential gum, mg/100 ml	61	37
Existent gum, mg/100 ml	25	3
Aniline-gravity product	4415	5054
Gravity, 60°/60° F		
Specific	0.861	0.849
A.P.I.	32.9	35.1
Reid vapor pressure, lb/sq in.	0	0
Hydrogen-carbon ratio	0.147	0.152
Net heat of combustion, Btu/lb	18,400	18,475
Aniline point, °F	134.2	144.0
Smoke-volatility index ^a	13.5	15.1
Smoke point ^b , mm	11.8	13.8
NACA K factor ^c	415	393

^aSmoke point plus 0.42 (percent by volume fuel boiling under 400 °F).

^bDetermined by method 2107 of Federal Specification VV-L-791.

^cRef. 7.

TABLE II. - SINGLE-COMBUSTOR CARBON-DEPOSIT AND EXHAUST-GAS-SMOKE DATA

Run	NACA base fuel	Additive	Additive concentration, percent by weight	Carbon deposit, g						Average carbon deposit, g	Average variation, percent	Change from base-fuel deposit ^b , percent	Exhaust-gas-smoke rating			
1	53-193	n-Propyl nitrate	0.5	25.9	32.4	29.4	33.5	---	---	30.3	8.8	-14.9	$\frac{1}{2}$	3	3	---
2		n-Propyl nitrate	1.0	34.4	35.3	---	---	---	---	34.9	1.3	-2.0	3	3	---	---
3		None	---	32.4	28.8	32.1	33.7	---	---	31.8	4.4		3	3	$\frac{1}{2}$	$\frac{1}{2}$
4		Iso-octyl nitrate	0.5	30.7	37.3	28.5	---	---	---	32.2	10.7	-9.6	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
5		Iso-octyl nitrate	1.0	30.8	21.2	25.5	22.1	---	---	24.9	13.0	-30.0	3	3	$\frac{1}{2}$	$\frac{1}{2}$
6		None	---	36.3	37.7	41.1	31.4	35.5	36.5	36.4	5.6		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
7		Amyl nitrate	0.5	24.3	25.7	29.9	---	---	---	26.6	8.1	-25.3	3	3	$\frac{1}{2}$	$\frac{1}{2}$
8		None	---	43.0	29.8	42.7	35.6	---	---	37.8	13.4		3	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
9		Amyl nitrate	1.0	26.8	30.0	21.1	---	---	---	26.0	12.4	-27.0	$\frac{1}{2}$	$\frac{1}{2}$	3	---
10		None	---	38.1	---	---	---	---	---	38.1	---		$\frac{1}{2}$	---	---	---
11	55-89	None	---	20.6	20.4	21.0	---	---	---	20.7	1.2	13.6	3	4	---	---
12		2-Nitropropane	3.5	22.5	---	---	---	---	---	22.5	---		4	---	---	---
13		None	---	21.1	---	---	---	---	---	21.1	---	56.6	4	---	---	---
14		n-Butyl nitrate	3.7	31.0	---	---	---	---	---	31.0	---		4	---	---	---
15		None	---	18.3	---	---	---	---	---	18.3	---		4	---	---	---
16		tert-Butyl hydroperoxide	3.1	19.0	---	---	---	---	---	19.0	---	-4.0	$\frac{1}{2}$	$\frac{1}{2}$	---	---
17		None	---	18.6	16.1	17.5	---	---	---	17.4	5.2		4	4	---	---
18		Nitrobenzol	4.2	19.7	---	---	---	---	---	19.7	---	-0.5	$\frac{1}{2}$	---	---	---
19		None	---	23.2	19.1	---	---	---	---	21.2	9.9		$\frac{1}{2}$	$\frac{1}{2}$	---	---
20		Amyl nitrite	2.76	22.1	---	---	---	---	---	22.1	---	11.6	4	---	---	---
21		None	---	21.4	20.4	---	---	---	---	20.9	2.4		4	4	---	---
22		Diethyl ether	2.5	15.5	---	---	---	---	---	15.5	---	-21.7	4	---	---	---
23		None	---	19.3	---	---	---	---	---	19.3	---		4	---	---	---

^aAverage variation of individual carbon-deposit values from average deposit value.^bAverage deposit minus over-all average base-fuel deposit.
Over-all base-fuel deposit

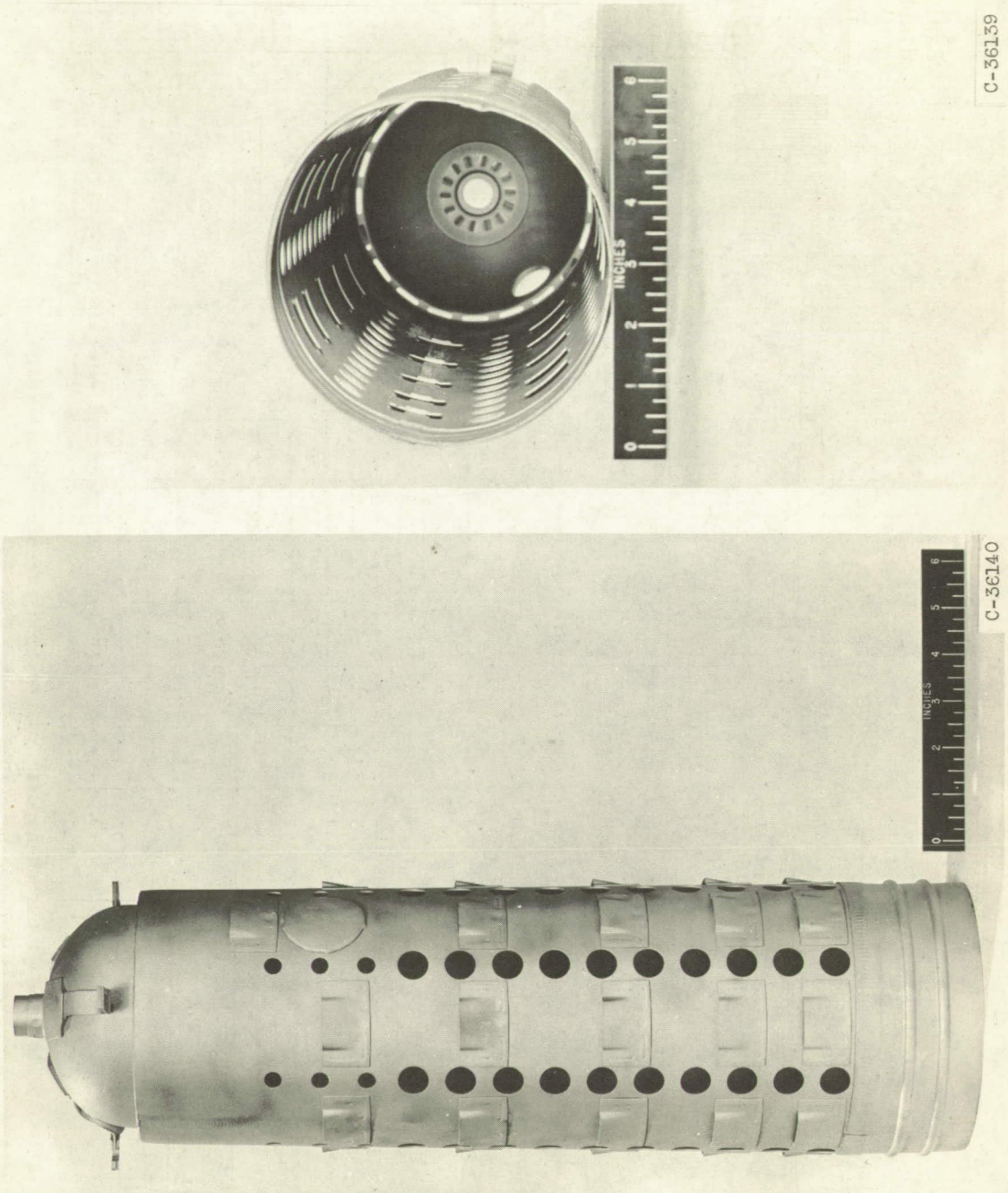


Figure 1. - Inner liner and dome of J33 single combustor used in carbon-deposition investigation.

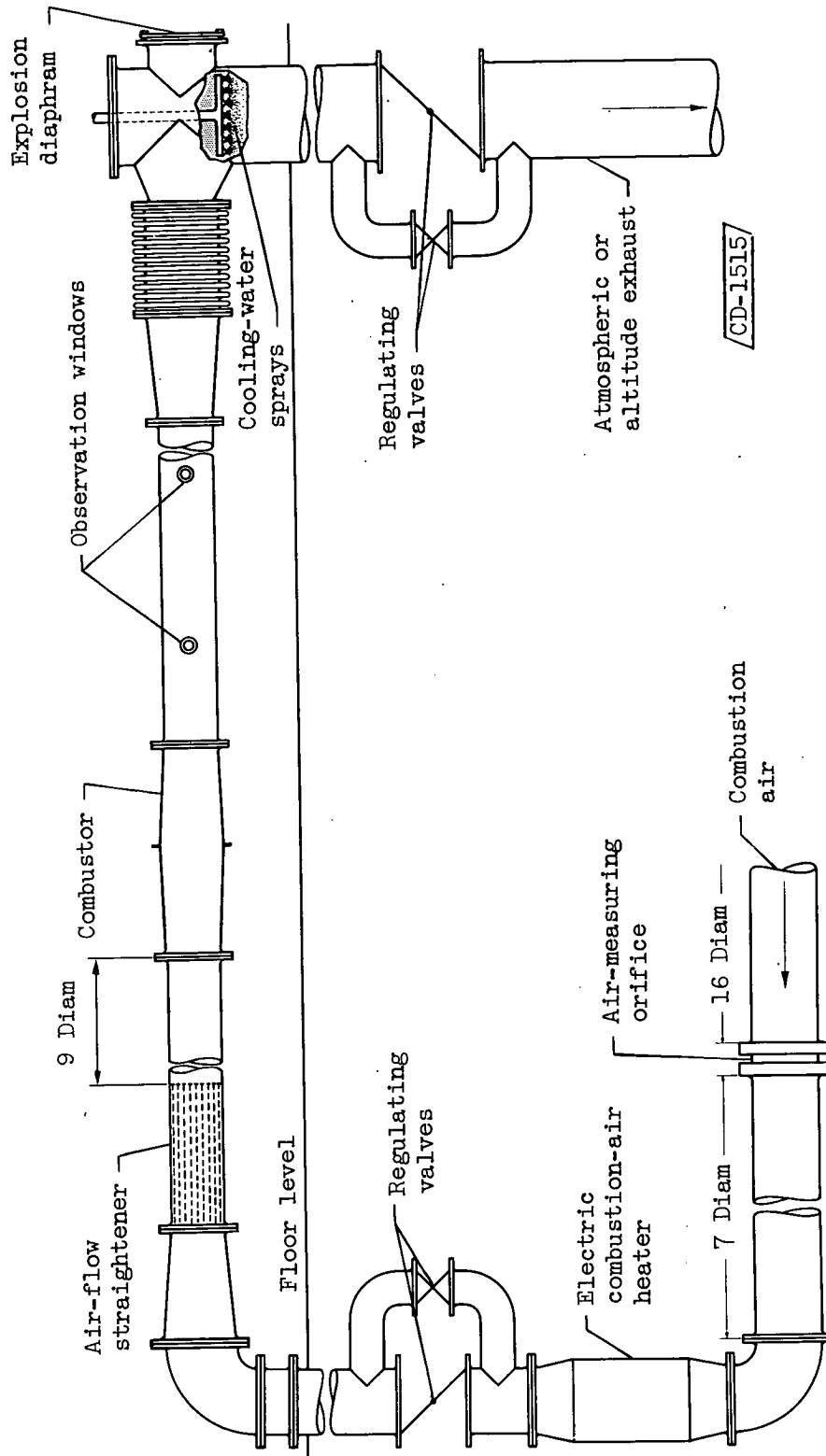


Figure 2. - Single-combustor installation and auxiliary equipment.

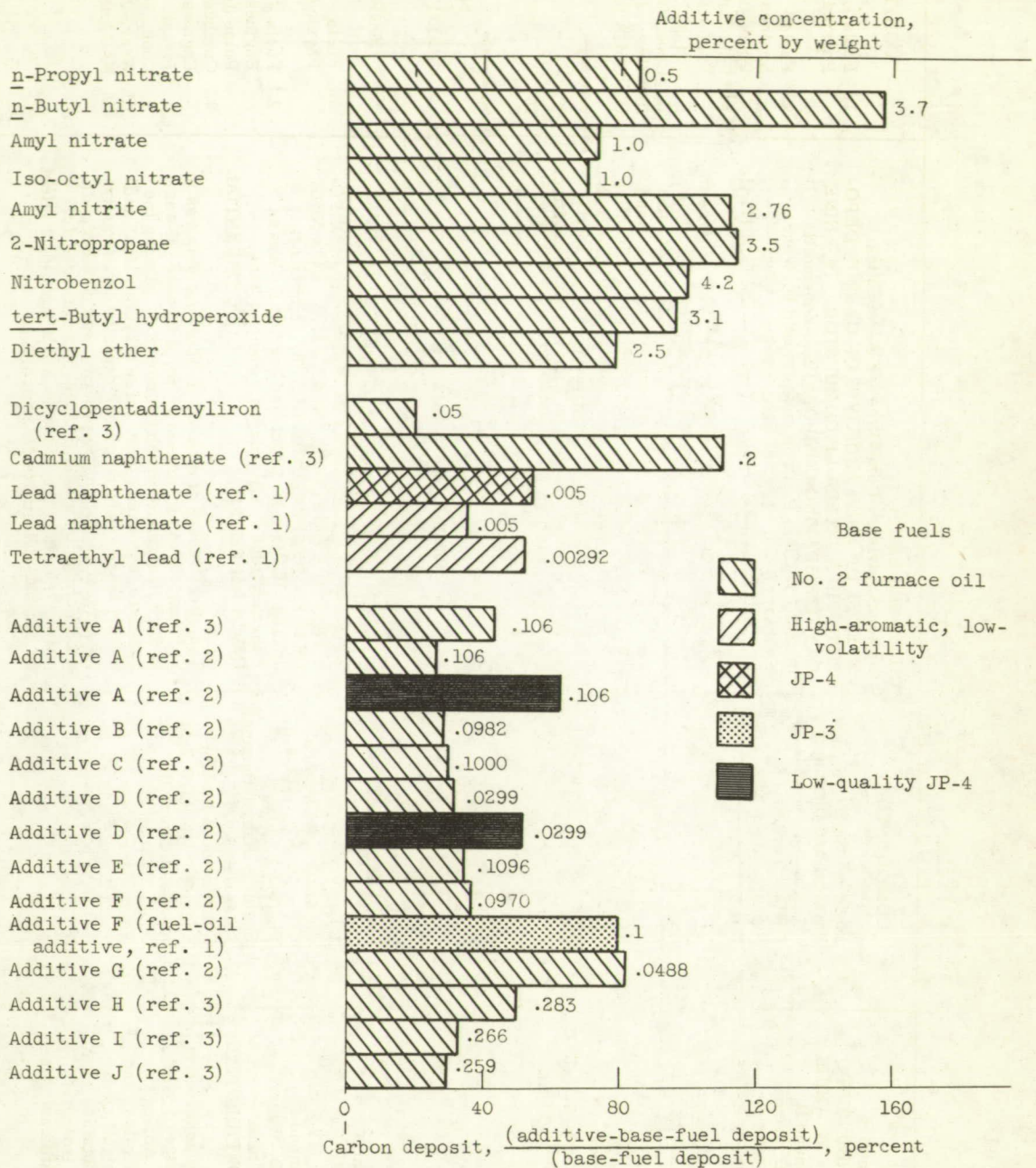


Figure 3. - Relative effectiveness of 23 additives for reducing turbojet-combustion-chamber carbon deposits.